Comments and Position Regarding the Joint Technical Bulletin "Department of Defense Ammunition and Explosives Hazard Classification Procedures" TB700-2, dated 5 January, 1998.

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ABSTRACT

When the Department of Defense (DoD) revised its hazard classification guidelines in Technical Bulletin (TB) 700-2, NAVSEAINST 8020.8B, TO 11A-1-47, DLAR 8220.1 dated 5 January 1998 [1], it significantly changed the procedures used to determine the explosive classification of rocket motors, to be shipped or placed in DoD storage facilities. The revised test protocols outlined in this document, (hereafter referred to as TB 700-2) are far more conservative and costly to implement than the previous ones.

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These changes will have a profound impact on the solid rocket community and in particular those involved with the research and development and manufacture of large rocket motors. The ramifications are higher development costs and severe limitations on performance improvements. This paper voices the concerns the solid rocket community has with the revised TB 700-2 test protocols for large rocket motors and outlines the current efforts of Thiokol, Air Force Research Laboratory Propulsion Directorate, Atlantic Research Corporation and Naval Air Warfare Center to unite the solid rocket community into developing acceptable alternate test protocols that could fulfill the intent of TB 700-2 and be considered by the Department of Defense Explosive Safety Board (DDESB) for incorporation into a future revision to TB 700-2.

INTRODUCTION

As early as 1989, the Joint Army-Navy-NASA-Air Force (JANNAF) Propulsion Systems Hazards Subcommittee (PSHS) and the Safety and Environmental Protection Subcommittee (SEPS) were jointly looking at the effects of critical diameter on shock sensitivity of large rocket motor propellants [2]. From 1991 to 1992, the Safety and Hazard Classification Panel of the PSHS developed a generic critical diameter and card gap test protocol for large rocket motor classification. The purpose of this protocol was to select the proper scale of gap test to be used based on critical diameter. Several of their findings were later incorporated into the 1993 draft of TB 700-2; however, none of the members of the JANNAF community recognized the subtle changes in the alternate test procedure gap test criteria of the 1993 draft, or the changes to the protocol. JANNAF wanted to use critical diameter to select the appropriate gap test. The protocol that was actually incorporated into the TB 700-2 draft document and later in the 1998 issued document, requires the performing of up to three GAP tests – not critical diameter tests. In addition, the pass/fail criteria (propagation at any gap or zero gap in any of the tests is to be hazard classified 1.1) were not specified by JANNAF; DDESB developed this independently with the tri-service hazard classifiers.

In April of 1999, government and industry members of the propellant formulation community became aware of recent changes in the Department of Defense Explosives Hazard Classification Procedures at the JANNAF Propellant Development & Characterization Subcommittee (PDCS) meeting in San Diego, CA. Unfortunately, many of the PDCS members do not attend the PSHS meetings. For many of the propulsion community, not having the background and insight that the PSHS members had on the evolution of TB 700-2, many felt taken aback and extremely concerned.

On May 26, 1999, the Space and Missile Defense Command (SMDC) sponsored a Hazard Classification Seminar in Huntsville, AL to present and clarify the revised TB 700-2 hazard classification procedures. Representatives from all of the major solid propulsion contractors and government labs attended this seminar. At the conclusion of the seminar, a subsequent meeting was held at Thiokol Propulsion in Huntsville to discuss the changes in the Department of Defense Explosives Hazard Classification Procedures and the ramifications of these changes to the solid rocket community. As a result of the Thiokol meeting and subsequent meetings sponsored by the JANNAF PSHS and PDCS, members from the propellant contractors and government laboratories have raised several concerns regarding TB 700-2, particularly as it applies to large solid rocket motors. Large rocket motors are defined in TB 700-2 as having a motor diameter greater than or equal to 304.8 millimeters ($\geq$12 inches). This paper outlines the required and alternate test protocols under TB 700-2, the concerns the solid rocket community has with them and makes recommendations for tests that could potentially satisfy the needs of both DDESB and the solid rocket community.

DISCUSSION

Description of Test Protocol

TB 700-2 describes the methods by which a substance or article is given a hazards classification (Class 1 explosive or not, and division of Class 1 – 1.1 through 1.6). The procedures call for a number of UN test series to be run, first on the substance, and then on the packaged articles. For materials to be used as propellants, or for rocket motors, one can go directly to UN test series 3.

UN Test Series 3 is run to determine whether or not the substance is too hazardous to transport in the form in which it was tested. It consists of four tests: Bureau of Explosives (BOE) impact, Allegheny Ballistics Lab (ABL) friction, thermal stability and small scale burning. The substance is considered too hazardous to transport in the given configuration if it fails to pass any one of these tests. If it fails the thermal stability test, it is considered too hazardous to transport unless it can pass the Thermal Stability Test for Articles and Packaged Articles of UN Test Series 4. If it fails any of the other Series 3 tests, it may be encapsulated and/or packaged and subjected to the 12-meter (39.37 ft) drop test of UN Test Series 4. If it passes that test, it is accepted as a Class 1 material. To pass the 12-meter drop test, the article may be ruptured, but it must not explode or ignite.

UN Test Series 5 is mandatory only for Hazard Division (HD) 1.5 materials, and is not generally applicable to propellants or rocket motors. UN Test Series 7 applies only for HD 1.6 materials. UN Test Series 6 is mandatory for HDs 1.1, 1.2, 1.3 and 1.4, and is the series that discriminates between these divisions. This test series consists of three tests: the single package test, the stack test, and the external fire test.

The **single package test** is designed to determine whether initiation or ignition in the package causes a burning or explosive reaction, and in what way those effects could endanger the surroundings. In this test, a detonator of sufficient energy to ensure ignition of the material is set off in the middle of the package. If the result is explosion of the total contents as indicated by:

a. a crater at the test site,
b. damage to the witness plate under the package,
c. measurement of a blast, or

d. disruption and scattering of most of the confining material (a minimum of 1-meter (3.28 ft) of sand on all sides);

then the product is given a Division 1.1 designation. The test is run three times. For substances that are intended to function by deflagration, the first test is initiated with a standard detonator, and the last two with an igniter. If the test sample is an article that has its own means of ignition, its own means of ignition is used. (This would be a static test if the article were a rocket motor.)

The **stack test** is used to determine whether burning or explosion in one package in the stack is propagated to the other packages, and in what way the surroundings could be endangered by this event. At least three articles are required for this test. As with the single package test, a detonator or igniter is used in the stack test to initiate one article. The other packages/articles are situated in the configuration in which they are to be shipped. The criteria for classification for the stack test are similar to those for the single package test. The basic criterion for a HD 1.1 designation is the explosion of virtually the entire contents of the articles. This is evidenced by:

a. a crater at the test site appreciably larger than that given by a single package,
b. damage to the witness plate beneath the stack which is appreciably greater than that from a single package,
c. measurement of blast, which significantly exceeds that from a single package, or violent disruption and scattering of most of the confining material (once again, a minimum of 1-meter (3.28 ft) of sand on all sides).

The final of the UN Series 6 tests is the **external fire (bonfire) test**, and is performed on a stack of packages as configured for transportation or storage. The procedure calls for a minimum of three packages to be supported on a frame and heated by wood or liquid fuel combustion at a rate consistent with what might result from a shipping accident. Three aluminum witness screens are set up 4 meters (13.12 ft) from the edge of the stack of articles. The outcome of this test allows materials to be classified as HD 1.1, 1.2, 1.3 or 1.4. If an explosion of the total contents of the package appears to occur instantaneously, the article is classified as HD 1.1. The articles are classified as HD 1.2 if debris from the event perforates any of the three aluminum witness plates, or if more than 10 metallic projections, each with a mass exceeding 25 grams (0.05 lbm) are thrown more than 50 meters (164 ft), or if a metallic projectile with a mass exceeding 150 grams (0.33 lbm) is thrown more than 15 meters (49.21 ft) from the edge of the stack. The product is assigned to HD 1.3 if it cannot be classified as 1.1 or 1.2, but any of the following four events does occur:

a. a fireball, which extends beyond any of the three witness screens,
b. a jet of flame, which extends more than 3 meters (9.84 ft) from the flames of the fire,
c. the irradiance of the burning product exceeds that of the fire by more than 4 kW/sq. m at a distance of 15 meters from the stack, or
d. fiery projections emanating from the product are thrown more than 15 meters from the edge of the stack.

If none of the events occur that would place the article into HDs 1.1, 1.2 or 1.3, then the article is classified as HD 1.4, unless it is determined there is no explosive hazard at all, in which case the product is considered for exclusion from Class 1.

Alternate Tests to UN Test Series 6

The authors of TB 700-2 were aware that testing large solid rocket motors per the UN Series 6 protocol is impractical. If the protocol were to be rigidly followed for the Space Shuttle, for example, UN Series 6 testing alone could cost tens of millions of dollars. A series of alternate tests was therefore designed for application specifically to solid rocket propellants and motors. For HD 1.3, TB 700-2 states: "Solid propellant rocket motors for which it is impractical to conduct the hazard classification tests given in Chapter 5 present special concerns. The following guidance for alternate testing is provided: The shock sensitivity of the propellants shall be measured at the diameter at which the material maintains a stable detonation (if at all) up to the web thickness for the rocket propellant or 203.2 millimeters (eight inches), whichever dimension is less."

The protocol is then given for testing the propellant at up to three different diameters. The first test is the UN Series 2 gap test. This test is conducted using a steel pipe with a 36.58-millimeter (1.44-inch) internal diameter (ID) and a length of 406.40 millimeters (16 inches). The steel pipe is filled with the propellant in question and placed on a 3.17-millimeter (1/8-inch) steel witness plate. A buffer of polymethyl-methacrylate (PMMA) cards, 50.80 millimeters (2 inches) in diameter by 50.80 millimeters long, are placed between the 50.80-millimeter diameter, 50.80-millimeter long pentolite booster to attenuate the shock into the propellant on the first test. A series of tests are run with variable amounts of cards down to a zero gap, where all of the shock is transmitted directly into the propellant. An acceptable and widely used alternate test for the UN Series 2 gap test, is the Large Scale Gap Test (LSGT), also known as the Naval Ordnance Lab (NOL) LSGT. The steel tube for the LSGT is 139.70 millimeters (5.5 inches) long, has a 36.58-millimeter (1.44-inch) ID and uses a 9.53-millimeter witness plate (3/8-inch). The LSGT configuration is shown in Figure 1.

If two of the following three detonation criteria are met, the propellant is classified as HD 1.1: a) a stable shock wave is maintained in the propellant as measured by its velocity, b) a hole is punched in the witness plate, or c) the pipe is split along its entire length. A negative response is shown in Figure 2.

If the propellant does not produce a positive response (detonation) in this configuration at zero cards, the second gap test (extremely insensitive detonating substance-EIDS) configuration is used. This test is also known as the Expanded Large Scale Gap Test (ELSGT) because it essentially doubles all of the hardware dimensions of the LSGT. For this test, the diameter of the sample is increased to a 73.02-millimeter (2.875-inch) ID, the length increased to 279.44 millimeters (11 inches) and it utilizes a 22.22-millimeter (7/8-inch) steel witness plate. The donor charge for the EIDS gap test is a 95.25-millimeter (3.75-inch) diameter x 95.25-millimeter tall pentolite booster. For the first test, a PMMA gap of 70.10 millimeters (2.76 inches) is used to attenuate the shock, then tests are run at varying cards down to zero as in the first test series. The EIDS test configuration is shown in Figure 3.

A clean hole or shattering of the witness plate is the criteria for this test as designating a propellant as HD 1.1 and an example of a positive test is shown in Figure 4.

If the propellant does not detonate in the EIDS configuration at zero cards, it is tested in the highly confined Super Large Scale Gap Test (SLSGT), with a propellant diameter up to 177.80 millimeters (7 inches) or the web thickness of the propellant, whichever is less [sic]. For this test, the diameter of the sample is increased to a 177.80-millimeter ID, the length increased to 406.40 millimeters (16 inches) and it utilizes a 38.10-millimeter (1.5-inch) steel witness plate. For the maximum 203.20-millimeter (8-inch) OD pipe, the donor charge is a 203.20-millimeter diameter x 203.20-millimeter tall Comp B booster charge. As with the previous tests, the SLSGT is a series of variable PMMA gap tests conducted down to a zero card gap, and once again, if a detonation is measured, the article is given a HD 1.1 designation. The SLSGT configuration is shown in Figure 5 and a positive test with crater is shown in Figure 6.

Figure 1. LSGT Configuration

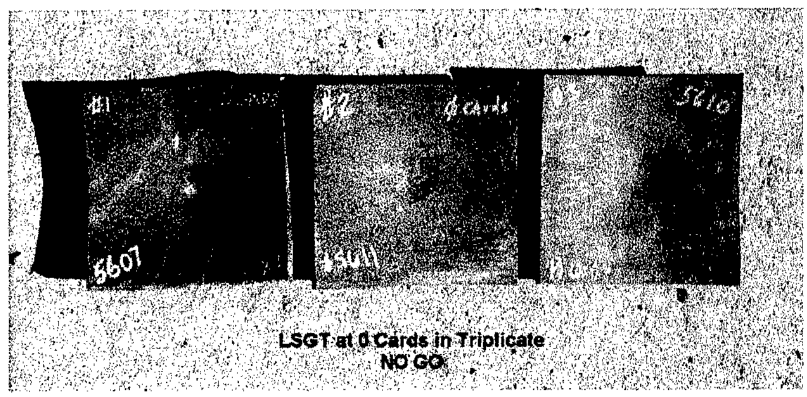

Figure 2. LSGT Negative Response

Comments on Protocol

It would appear that the nominal protocol for determining the hazard division designation was developed with relatively small articles in mind. The article tests outlined are reasonably practical for most munitions and small tactical rocket motors. However, the single package, stack and bonfire tests are prohibitively expensive for large solid rocket motors. As mentioned above, the authors of TB 700-2 recognized this and the set of alternate tests was developed.

Figure 3. EIDS/ELSGT Test Configuration

Figure 4. EIDS/ELSGT Positive Response

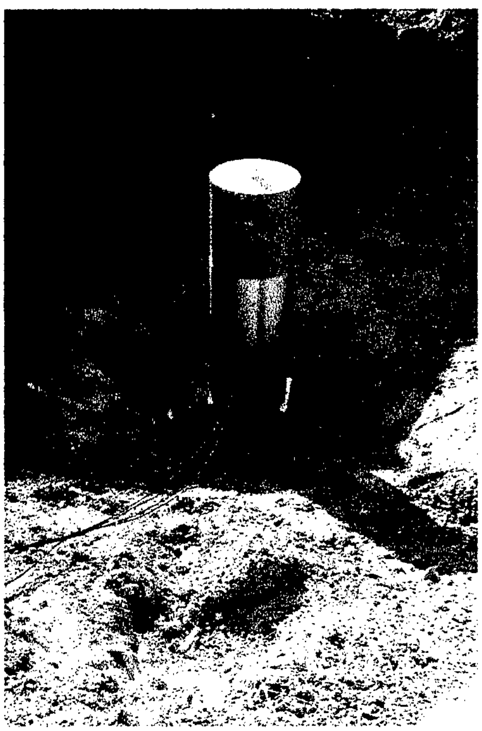

Figure 5. SLSGT Configuration

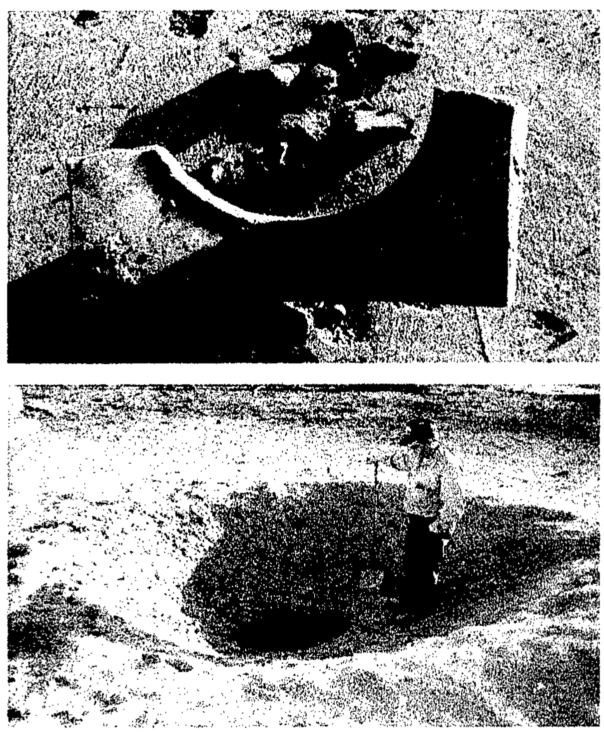

Figure 6. SLSGT Positive Response and Crater From Test

The solid rocket community does not have a problem with the concept of alternate tests to be used in place of the nominal protocol. This only makes sense given the impractical nature of conducting those tests on full-scale rocket motors. Rather, the concern is with the nature of those tests. The major problems from a solid rocket perspective are that the alternate tests are virtually unrelated to the nominal tests that they are designed to replace, and that they are far too stringent to represent a reasonable storage or transportation hazard.

The nominal protocol tests are not nearly as severe in their measurement of detonation shock sensitivity of substances or articles as the alternate tests. The UN Test Series 6 protocol requires a standard No. 8 detonator (pentaerythritol tetranitrate (PETN) initiated by dextrinated lead azide) to initiate the article. This detonator contains only 0.5 g (0.02 ounces) of material, which is a far cry from the approximately 10 kilograms (22 pounds) of material in a 203.20-millimeter (8-inch) diameter x 203.20-millimeter long Comp B booster charge. The alternate tests to discriminate between HDs 1.1 and 1.3 are strictly related to detonation shock sensitivity and are subject to much more severe stimuli than occurs with the baseline testing. The bulk of the nominal tests focus on the tendency of an article to explode when subjected to an unplanned ignition. It thus seems likely that performing the alternate test protocol would often give a different hazard designation than would result from following the nominal test protocol, since they are testing for two different threat conditions (shock stimulus vs. ignition stimulus).

Historically, propellant detonability has been used as a discriminator between HDs 1.1 and 1.3. The dividing line between negative and positive test results has been at 70 cards (0.70 inches) in the NOL card gap configuration, or with a 'go' or 'no go' response to a #8 cap test with a lead cylinder witness plate. In fact, both of these tests continue to be discriminating criteria per TB 700-2 in assigning a material an interim hazard classification (IHC). In terms of critical diameter (D_c), i.e., the propellant grain thickness that can maintain a stable detonation, a 69-card propellant, which would have an IHC of HD 1.3, would likely have a D_c of about 63.50 millimeters (2.5 inches). Under the alternate test protocol given in TB 700-2, for large solid rocket motors, the dividing line between HDs 1.1 and 1.3 is moved to a D_c of about 355.60 millimeters (14 inches)[1], or about an order of magnitude change.

Implications to the Solid Rocket Community

The implications of such a large change in the definition of the hazards divisions are profound. Many of the HD 1.3 propellants currently used by the U.S. DoD would be reclassified HD 1.1 in their manufactured configurations if placed into new fielded DoD systems. This has been demonstrated in a current missile defense program. The motor and its propellant were originally classified as a HD 1.3 with a Department of Transportation (DOT)

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[1] Critical diameter is defined as the propellant thickness that will maintain a stable detonation when the propellant is in an unconfined condition. Confining the propellant within a strong container can result in detonations at diameters as small as ½ of the unconfined propellant. Thus a propellant with a less than 355.60 millimeter (14-inch) Dc would be likely to give a 'go' result in a 177.80-millimeter (7-inch) ID SLSGT in which it is confined by a 12.70-millimeter (½-inch) steel wall, particularly when it is given the relatively short run distance of 406.40 millimeters (16 inches).

IHC over ten years ago and had received DoD interim hazard classifications of 1.3 up until 1998. However, because the motor was being used in a new, fielded DoD system, it no longer qualified for an IHC and was subjected to the rules of TB 700-2. When the propellant was subjected to the SLSGT, it failed and received a HD 1.1 designation under the TB 700-2 alternate test protocol.

Because the quantity distance requirements for HD 1.1 materials are significantly more stringent than for HD 1.3. This has a direct impact on cost of facilities, land and transportation. In fact, when the above mentioned propellant failed the SLSGT and became a 1.1 material, the prime contractor had a life cycle cost analysis conducted and determined it was cheaper by tens of millions of dollars, to reformulate and requalify a new propellant for the motor than it was to accept the 1.1 designation and incur the additional storage and transportation costs. Given the deeply set reticence of many organizations, such as launch facility range safety, to even consider handling or storing HD 1.1 materials, it is likely that many more previously acceptable propellant formulations would be precluded from being used. Figure 7 shows the quantity distance limits of class 1.1 vs. class 1.3 materials for inhabited building distance [4].

The question of 'grandfathering' raises immediate concerns. If currently fielded systems that have been classified as HD 1.3 are required to be reclassified according to the protocol of the January, 1998 TB 700-2, many will drop to HD 1.1 or HD 1.2, as seen in the missile defense motor. In addition to the cost of testing all of these systems, there will be major repercussions in their storage and handling. If current systems are 'grandfathered', and do not require testing under the new protocol unless they are placed into a new DoD system, the situation will arise in which new systems that are insignificantly changed in terms of real hazards from old systems will have a different hazard classification. If there actually is a good reason to adapt the new protocol, i.e., the former protocol was inadequate in determining the real storage and handling hazards of an article, then it is very difficult to justify 'grandfathering' existing systems.

Such a change might be warranted if there were data or incidents to show that the former 70-card dividing line was resulting in unsafe storage or transportation conditions. However, no such data exist. The shock stimulus imparted to the propellant sample in the NOL test at 70 cards is approximately 70 kbars (1,015,264.21 psi) [5]. With the zero card requirement for the LSGT, the shock stimulus is approximately 280 kbars (4,061,056.83 psi) [6].

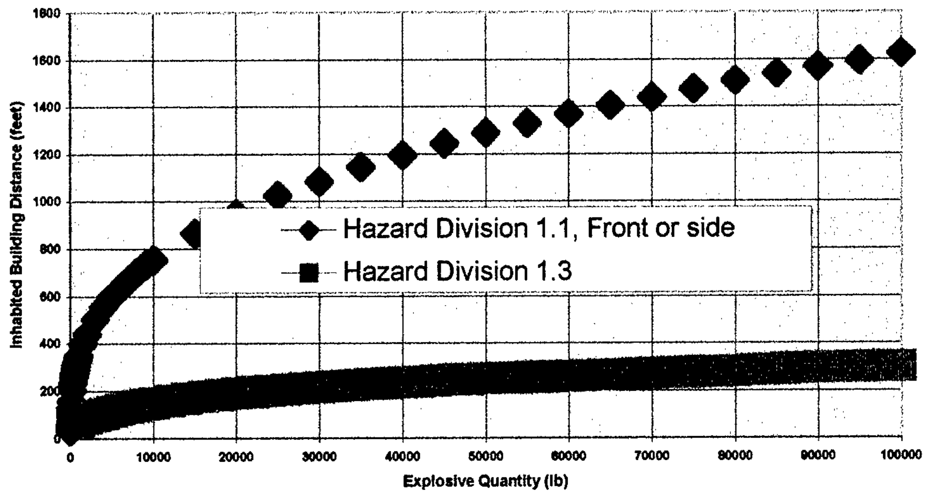

Figure 7. Quantity Distance Limits: Inhabited Building Distance, 1.1 vs. 1.3

For the SLSGT at zero cards, the shock stimulus is greater than 280 kbars (4,061,056.83 psi). It is difficult to imagine a storage or transportation scenario that could result in a solid rocket motor receiving a shock of that magnitude. To put things in perspective, fragments hitting a rocket motor from an adjacent explosion would produce less than 1 kbar (14,500 psi) of shock pressure. One author (Graham) had previously estimated that if two rocket motor transport trucks each traveling at 96.56 kilometers/hour (60 mph) collided head-on, the shock pressure into the motor should be less than or equal to 0.3 kbar (4,351.13psi). The following analysis further illustrates this scenario with the entire potential shock stimulus of the impact directed into the rocket motor with none of the shock attenuated by the two trucks. The Standard Multi-material Eulerian Reactive Flow (SMERF) reactive hydrocode was utilized to assess the shock loading into a large rocket motor in a transportation accident. The SMERF calculation involved a 1.22-meter (4-foot) diameter by 2.44-meter (8-foot) long steel cased motor with a central perforation impacting a 0.30-meter (1-foot) thick by 1.37-meter (4.5-foot) wide plate of solid steel at 193.12 kilometers/hour (120 miles/hr). Rather than use a typical class 1.3 propellant that contains no explosive ingredients, the motor was loaded with a relatively shock sensitive plastic bonded explosive (PBX), containing cyclotrimethylenetrinitramine (RDX), aluminum (Al), and hydroxy-terminated polybutadiene (HTPB) binder. The analysis was run to determine whether shock initiation would occur as a result of the impact. The setup is shown in Figure 8. Pressure and mass-fraction reacted were recorded as a function of position and of time.

A typical pressure contour plot is shown in Figure 9. and the pressure-time history is shown in Figure 10. The rocket motor never experiences more than a 2 kbar (29,007.55 psi) shock in the explosive load, and it doesn't transition to detonation, even with this shock sensitive explosive replacing the propellant.

With the adoption of TB 700-2 as currently constituted, most of the insensitive munitions (IM) projects would be invalidated. It has been found that propellants that do the best in response to the IM stimuli are those with energetic binders and/or plasticizers, which often contain low levels of nitramines. The IM tests were designed to specifically address the threats that rockets might face in combat. In order to be IM compliant, the motor must not explode or detonate in response to any of IM test stimuli (bullet and fragment impact, fast and slow cookoff, etc.). It is difficult to believe that a motor would be considered unlikely to explode in a combat zone, but be classified as susceptible to explosion during storage or transportation (HD 1.1). Also affected would be the Integrated High Payoff Rocket Propulsion Technology (IHPRPT) propellant projects, which seek to increase the performance of propellants over current 1.3 formulations. These propellants almost all have a HD 1.3 requirement, and are generally near or slightly above the zero-card boundary in the NOL Card Gap test. They would almost certainly fail to pass either the zero cards EIDS test or the SLSGT and thus be classified as HD 1.1.

Finally, the fact that TB 700-2 permits the 70-card NOL Card Gap boundary to be used for assigning a substance an IHC is inconsistent with the alternate testing outlined for the final hazards classification. Thus, there will be many substances that have a HD 1.3 IHC that will later be given a HD 1.1 designation when incorporated into an article of any size. This is very troubling from a development point of view, since a screening test is used that is much less severe than the final hazards designation test.

Other DoD organizations and solid propulsion contractors have expressed concerns similar to those mentioned here and are developing their own positions on the matter. One additional concern expressed by the solid rocket community regarding the nominal protocol (not the alternate tests) is that unground ammonium perchlorate (AP) might be classified as a Hazards Division 1.1 explosive. This would not only invalidate extensive studies performed by the Tri-Services, NASA and industry, that justified classifying unground AP as an oxidizer, not an explosive, but would also result in a multimillion dollar cost to comply to the storage and handling requirements of HD 1.1 materials [7-9].

Solid Rocket Community (PDCS & PSHS) Perspective

The following perspective is based on the summary of the JPM Workshop on TB 700-2, written by Edwin Mulder (CPIA, PDCS technical representative) [10]. In December of 1999 at the JANNAF 49th Joint Propulsion Meeting (JPM) in Tucson, AZ, a joint workshop was held as a cooperative effort between the JANNAF PSHS and PDCS subcommittees to address the impact of the revised TB 700-2. The intent of the workshop was to take the attendees individual technical concerns, objections and recommended alternate test protocols and form a consensus position and recommendation to the DDESB and Tri-services DoD Hazard Classifiers.

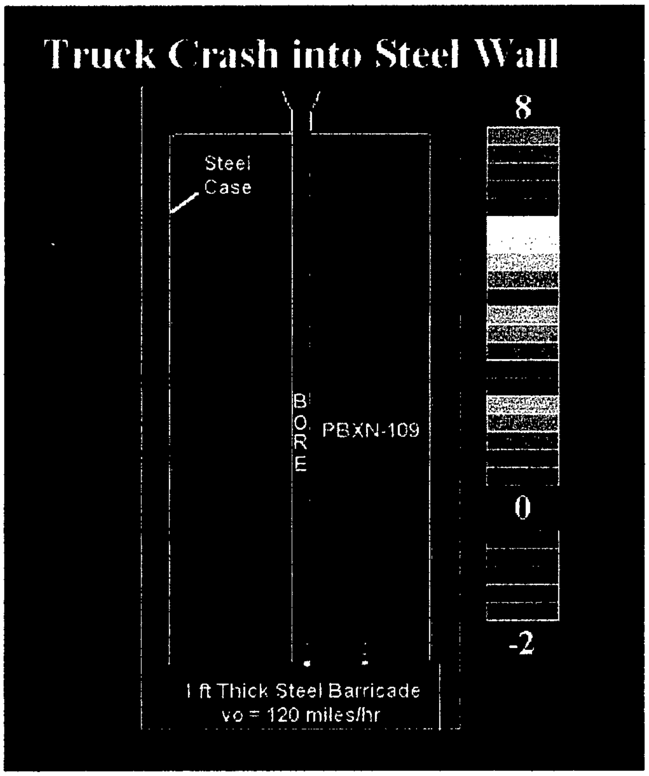

Figure 8. Set-up for SMERF Code Calculation.

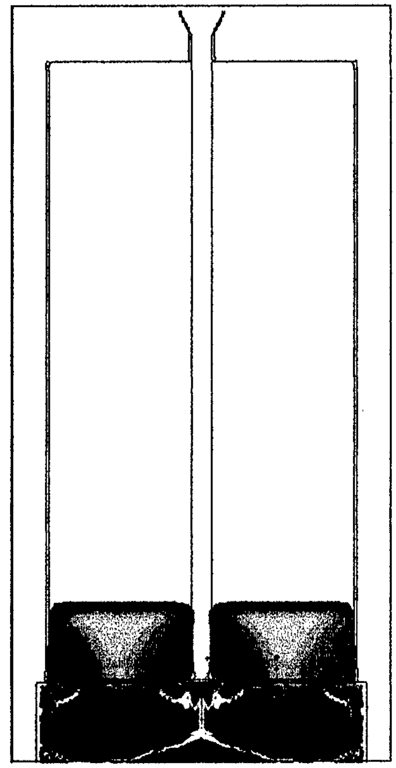

Figure 9. Pressure contours at 150 us. Green is compression, blue is tension. Maximum pressure in propellant is 2 kbar.

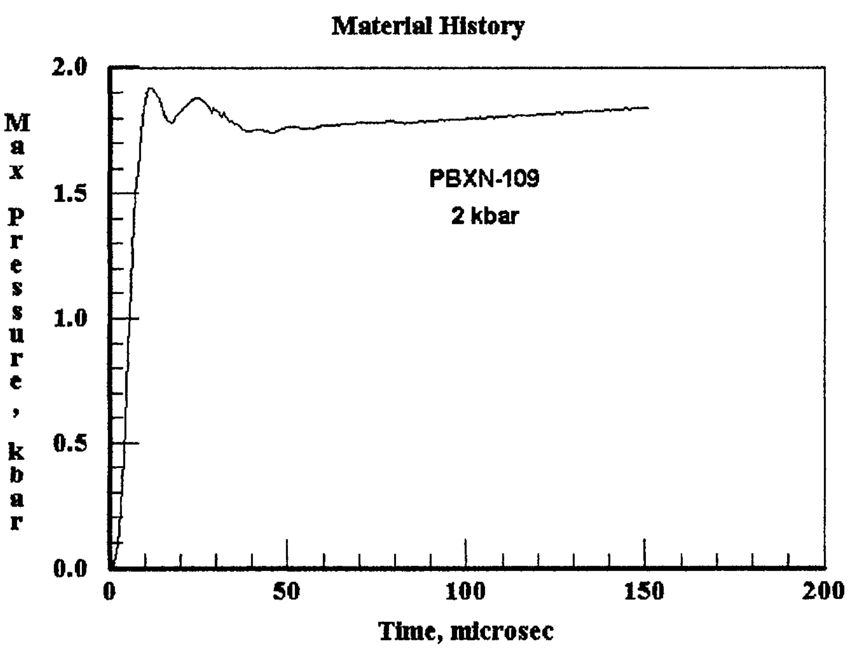

Figure 10. Pressure-time history into propellant.

The concerns voiced by the PDCS formulators and the PSHS system safety/hazards members were consistent with the ones mentioned in this paper and the additional concern that the TB 700-2 "alternate tests" are attempting to re-define solid propellant hazards based on the zero card SLSGT. The SLSGT is a test that all of the formulators and many in the safety and hazards community feel is an unreasonable and severe over-test requirement. The argument against the SLSGT, is that this change marks the beginning of a new philosophy of hazard testing and represents a significant change in the historical metric used to determine a solid propellant's DoD hazard classification. TB 700-2 (1/5/98) introduces two different test results with two different "metrics" to discriminate between propellant hazards (NOL card gap) versus rocket motor hazards (SLSGT). To the propellant formulators, hazard classification does not necessarily mean that 1.1 propellants are more dangerous than 1.3 propellants. In fact, most formulators agree that because 1.1 propellant articles are harder to burn (ignite) compared to Class 1.3 propellants, the potential mass fire hazard risk to personnel and facilities from an unplanned ignition may actually be much greater from articles classified as 1.3. Historical records support that more accidents have occurred with Class 1.3 propellants than 1.1 propellants.

A fundamental difference between the propellant formulators and many in the safety/hazards community is the question of whether a propellant/rocket motor can detonate. The safety and hazards community want to know if a detonation can be ruled out under any circumstances. The formulators, who are driven by performance as well as cost and safety, want to know if a detonation can be ruled out under any real-world, credible storage and transportation scenarios. The position of the propellant formulators and shock physics experts is that based on test data, a "credible incident" shock input range for a rocket motor under storage and transportation conditions would be 2-3 kbars (29,007.55-43,511.32 psi) maximum. Therefore the SLSGT shock input is greater than an order of magnitude over any "credible incident".

While an overall consensus position was not reached, the workshop attendees agreed to recommend that TB 700-2 (1/5/98) alternate test protocol requirements be revised to include the following:

1. Continue NOL card gap test requirement of 70 kbar (1,015,264.21 psi), at 70 cards for obtaining a storage and transportation interim hazard classification.
2. Include a Safety Hazard Analysis in the TB 700-2 requirements prior to assigning a final classification of articles
3. One of the following approaches:
    a. Continue to require SLSGT sample size, hardware and test setup and revise the donor charge output to a "credible incident" value, i.e. from >280 kbars (>4,061,056.83 psi) to 2-3 kbars.
    b. Continue to require SLSGT hardware configuration and include a significant separation [355.60 millimeters (14 inches) of PMMA] between the sample and the donor charge to attenuate the donor charge output to a "credible incident" value (from >280 kbars to 2-3 kbars).
4. Revise the test set up requirements to specify a 70 kbar donor charge and not change from the zero card requirement. This would require actual testing to validate the revised donor charge, however, it could be accomplished in a short

period as a round robin JANNAF activity. Several members of the workshop prefer this approach because it is consistent with the US/NATO NOL card gap test requirements. Include a Safety Hazard Analysis in the TB-700-2 requirements prior to assigning a final hazard classification of articles.

5. Eliminate the required SLSGT from the alternate test protocol and revise TB 700-2 (1/5/98) to include a different testing method of determining the critical diameter of the propellant. The requirement to conduct the NOL card gap test for an interim hazard classification should remain the same.

DDESB Perspective

On 22 February 2000, three of the authors of this paper, and two JANNAF representatives from John Hopkins University (JHU) / Chemical Propulsion Information Agency (CPIA), held a meeting with Dr. Jerry Ward and Dr. Josephine Covino at the DDESB headquarters in Alexandria, VA. The purpose of the meeting was to continue the open communication between the DDESB and members of the solid rocket community, where both parties could discuss their points of view and perspectives on the revisions to TB 700-2. Dr. Ward and Dr. Covino listened to our concerns about the inconsistencies between UN Test Series 6 and the alternate shock sensitivity tests. Dr. Ward agreed that UN Test series 6 and the alternate shock sensitivity tests do test for different threat conditions, i.e., unplanned ignition and fire vs. shock stimulus. However, he stated the main storage and transportation threat was detonation due to fire. That is why the cookoff test requires a full-scale article. Dr. Ward's rationale for the severity of the alternate shock sensitivity tests is that, if the sub-scale samples would not detonate under such a severe shock stimulus, they would not detonate under an unplanned ignition/fire scenario. After much discussion, it became clear that the DDESB desires data on both the shock sensitivity and the response to fast cookoff (bonfire test) for hazard classifying new articles.

Thiokol, Air Force Research Laboratory Propulsion Directorate, Atlantic Research Corporation and Naval Air Warfare Center position

Based on the notes from past meetings of the JANNAF Safety and Hazard Classification Panel of the PSHS and past proceedings compiled and distributed by CPIA, it is apparent that many others have recognized the need for other alternate tests to address the properties measured by those of UN Test Series 6. However, it appears that although these other tests were discussed, a consensus could not be reached, so they were not recommended for incorporation into TB 700-2. The failure to reach consensus has become a recurring theme and no doubt is caused by the differing perspectives between the systems safety/hazards members and the propellant formulators.

This collaborative effort between Thiokol, Air Force Research Laboratory Propulsion Directorate, Atlantic Research Corporation and Naval Air Warfare Center is a proactive attempt to unite the systems safety/hazards members and propellant formulators within the solid rocket community and reach a consensus for alternate testing.

RECOMMENDATIONS

For large solid rocket motors, there are three types of tests that are applicable to the intent of TB 700-2, and making the distinction between Hazard Division 1.1 and 1.3. The consequences of a) an unplanned internal ignition, b) extended exposure to an external fire, and c) the motor being subjected to a shock must be evaluated. UN Test series 6 addresses the first two of these, but the test requirements are prohibitively expensive. The third is evaluated to some degree in that the first single package test is initiated with a small detonation, but perhaps not adequately for some parties. The alternate tests that include the LSGT, EIDS and SLSGT address the question of shock sensitivity, however, because of the zero cards requirement of these tests, they represent an unrealistic shock stimulus for any conceivable transportation and storage hazard, but treat neither of the first two ignition events.

It is our position that the following potential alternate tests could satisfy the intent of TB 700-2. Specifically, we recommend that these tests constitute the nominal series of tests to comply with paragraph 41.3.3 in the parent document, UN ST/SG/AC.10/11 "Recommendations on the Transport of Dangerous Goods", which states that an alternate series of tests can be used if "The product including packaging can be unambiguously assigned to a hazard division by a qualified explosives expert on the basis of results from other tests or of available information."

POTENTIAL ALTERNATE TESTS

The following three alternate tests would adequately address the intent of TB 700-2, and yet not be prohibitively expensive. In addition, these tests address the DDESB desire to have data on both the shock sensitivity and the response to fast cookoff (bonfire test) for hazard classifying new articles. The details of each test would need to be further defined, but the following outlines each and offers potential off-the-shelf (or nearly so) test devices.

Internal ignition concerns:

Alternate test: As documented by the DDESB-KT memorandum of 7 Feb, 1999, a JANNAF proposal for using motor firing data for ignition function in lieu of single package hazard testing was approved by the Tri-service hazard classification group. This combined with item 3 below that addresses shock sensitivity should adequately address the purposes behind the single package tests from UN Test Series 6. This same DDESB-KT memo also states that 'large motors should be tested singly (if transported singly); however, storage configurations may require that multiple items be tested.' Thus, the stack test is not generally applicable to large solid rocket motors, and an alternate test protocol is probably not necessary.

External heating concerns:

Alternate test: Analog fast cookoff test. This would be essentially the same test called for in the current TB 700-2 Test 6(c), paragraph 5-7c [or the alternate test 6-6e(2)], but instead of being performed on a full-scale article, it would be performed on a subscale analog. The requirements for the analog would be that the thermal gradient during heating in a bonfire, the pressure within the vessel upon propellant ignition and the case burst pressure match the full-scale article as closely as possible. This could be accomplished by using the same case/insulation/liner/propellant materials used in the full-scale article, and by designing the analog case strength and opening size to match the nominal burst and operating pressures of the full-scale article.

For a given burst strength, the case thickness of a small diameter article is less than that of a large diameter article, so without modification, the thermal gradient would be different. However, the analog case could be further insulated with non-structural case material to supply the proper thermal environment. The web thickness used in such an analog would be a matter for discussion, but something similar to the 203.20-millimeter (8-inch) diameter Shrike motor that the Navy has used for several years for IM testing should be sufficient. This motor would have the added benefit of a large existing database for comparison. The aforementioned DDESB memo states "Alternate test data such as subscale engulfing fire test is acceptable (if verified as a model) as replacement for bonfire test of full-scale test article. The alternate test article approach requires further work to justify its use." Thus the DDESB has already taken the position that an analog fast cookoff test is an acceptable alternate test in principle.

Shock sensitivity concerns:

The only shock sensitivity test required by TB 700-2 for UN Test Series 6, is the detonator cap initiation on the first test run of the single package test. Many parties have expressed concern that this test is insufficient for discriminating between HD 1.1 and 1.3 articles. It is for this reason that the JANNAF Safety and Hazard Classification Panel developed the generic critical diameter and card gap test protocol for large rocket motor classification back in 1992. However, gap tests with unrealistic shock stimuli (zero card requirements) were adopted instead. The critical diameter tests and card gap tests at variable card levels could be used to build a database and gain insight into detonation phenomena in solid rocket motors. There is no possible credible event associated with storage, handling and transportation that corresponds to the >280 kbars (>4,061,056.83 psi) of shock the zero card SLSGT applies to the propellant. If one were to insist on such a large diameter sample in order to address possible critical diameter concerns, it would be important to provide a more reasonable confinement and shock input to the sample than is currently required by the zero card SLSGT. The original JANNAF intent to use critical diameter as a means for determining which shock sensitivity test to perform and to actually measure the shock pressure required for propagation (as measured by varying the gap) is a way of obtaining the data needed to allow experts to make informed decisions about the recommended shock sensitivity test configurations, sample dimensions, input charge dimensions and stand-off distance (attenuation).

Until the critical diameter testing can be completed, and a database can be generated, a practical approach would be to use the historical boundary between Class 1.1 and 1.3 propellants in regard to shock sensitivity. This has been the 70-card NOL gap test at 70 kbars (1,015,264.21 psi) of shock stimulus over an area of 36.58 millimeters (1.44 inches). This represents an over estimated, conservative approach to potential threats, but has served the industry well for over thirty years. However, the shock input over a 177.80-millimeter (7-inch) ID area for a SLSGT should be similar in duration but significantly less in magnitude, certainly no greater than 5 kbars (72,518.87 psi). In order to achieve this exposure in the SLSGT, a gap of approximately 355.60 millimeters (14 inches) of PMMA cards would be required to attenuate the magnitude of the shock from the booster charge down to that level. Additionally, the length of the booster charge would need to be shortened considerably from the 203.20 millimeters (8 inches) of the current SLSGT configuration to make the duration of the shock wave comparable to that of the NOL Gap Test. Similarly, if the EIDS test is utilized, it should have a reasonable shock stimulus such as the 70.10-millimeter (2.76-inch) PMMA gap used in UN Test Series 5. To address the issue of confinement, substitutes for the thick walled cylinders could be used. Many large-scale shock sensitivity and critical diameter tests have been conducted by the Air Force using cardboard cylinders.

Two other shock sensitivity tests could be used as a screening tool to assess critical diameter and gain insight into which diameters to test. They are the unconfined cylinder critical diameter test, which utilizes a sample 152.40 millimeters in diameter by 457.20 millimeters in length (6-inch x 18-inch). This configuration is shown in Figure 11. The second test is the conical critical diameter test that utilizes a 203.20-millimeter to 101.60-millimeter (8-inch to 4-inch,), sample with a 4 degree taper, shown in Figure 12.

For the present, a workable solution for shock sensitivity testing would include using the 70-card NOL LSGT gap test as a starting point. Then for those applications that have specific shock sensitivity/critical diameter concerns such as large motors with propellants containing energetic ingredients, shock sensitivity tests could be conducted and reviewed by experts in detonation behavior. These tests could include modified versions of the EIDS and SLSGT with reasonable shock inputs as seen in Figure 13.

Figure 11. Unconfined Cylinder Critical Diameter Test

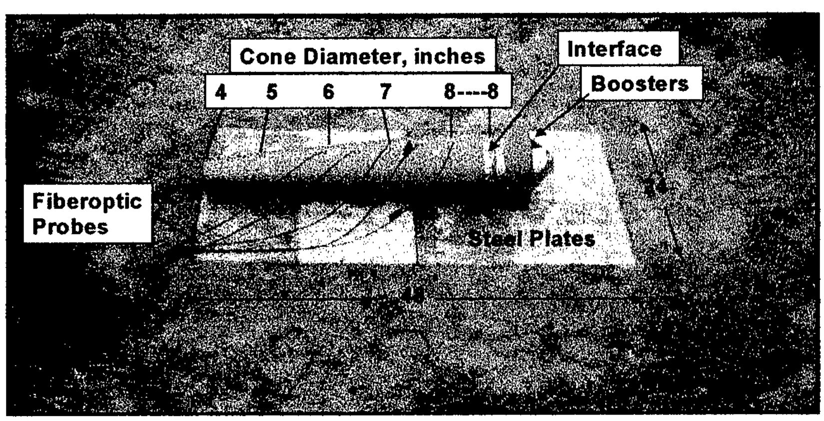

Figure 12. Conical Critical Diameter Test

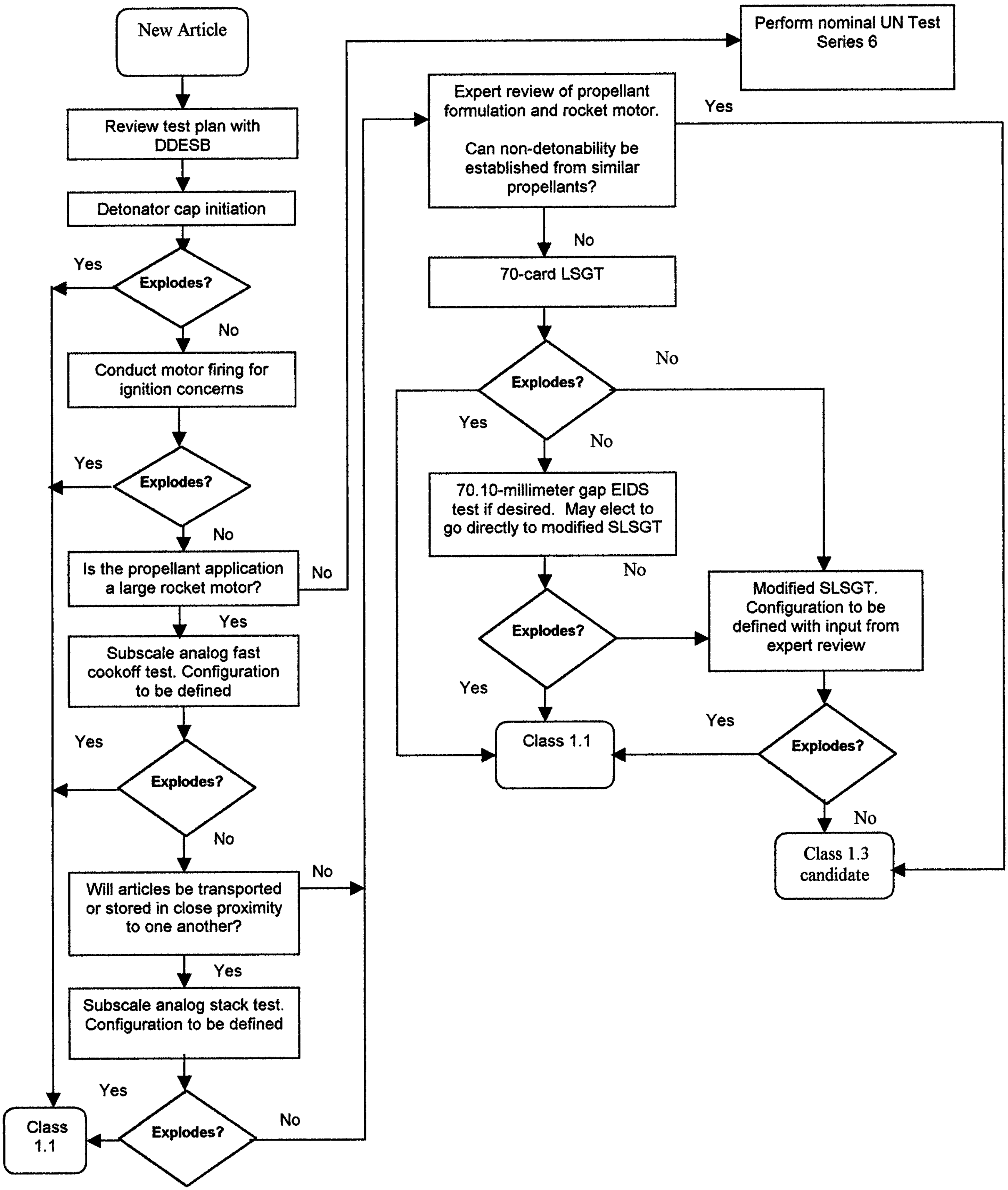

Figure 13. Proposed alternate hazard classification procedures for solid rocket motors

Threat hazard assessment

Before initiating any test protocols for hazard classification, what is clearly needed is a thorough threat hazard assessment for the intended materials or articles. By assessing the potential storage and transportation threats the articles could be subjected to, the appropriate test protocols could be implemented to address the concerns of: internal ignition, external fire and shock sensitivity/critical diameter. For example, if the end item is a large rocket motor that would be singly shipped and stored, then a stack test would not be required. Another example would be, if the end item were a large rocket motor containing nitramines such as RDX (cyclotrimethylenetrinitramine) or HMX (cyclotetramethylenetetranitramine). To adequately address the shock sensitivity/critical diameter concern, a conical critical diameter test, EIDS and SLSGT with a reasonable shock inputs would be called for, as well as a review by experts in detonation behavior. A full threat hazard assessment of the potential shock incidents that a large solid rocket motor could experience, with some margin of safety, would likely further reduce the severity of the shock input required for the hazard classification of a rocket motor.

FUTURE WORK

For the solid rocket community to come to a consensus and develop a standard protocol will require workshops, manpower and funding investments. This process was started at the JANNAF PDCS & SEPS Joint Meeting (8-12 May 2000). A workshop was held to specifically address what the recommended configuration of a shock sensitivity test should be. Items considered included sample dimensions, input charge dimensions (diameter and length) and stand-off distance (attenuation). The consensus of the workshop was that all of the shock sensitivity tests should be attenuated down to 70 kbars (1,015,264.21 psi) as a minimum and possibly much lower for the SLSGT. In addition, the test data from the SLSGT supports the belief that the sample length needs to be doubled to allow either the propagation of a stable detonation reaction or the decaying of the reaction to sonic velocities. Two of the authors (Boggs and Graham) have been actively conducting shock sensitivity testing (to address sample dimensions and attenuation) at their respective facilities and offered to present their data and recommendations in a joint workshop at the 29th DoD Explosives Safety Seminar held in New Orleans (18-20 July 2000). Also planned for this workshop will be discussions on subscale analog cookoff specimens.

The intent is to develop subscale tests articles that could be designed, tested and modeled to give the DDESB confidence that subscale articles can adequately correlate with the full-scale articles required in UN Test Series 6. Items to consider include how to best match the full-scale articles in terms of case burst pressure, case and insulation materials, and thermal gradients during the cookoff event and analog dimensions. Organizations identified as potential invitees include:

Aerojet
Alliant Techsystems

Air Force Research Laboratory (Propulsion Directorate) – Edwards AFB
Air Force Research Laboratory (Munitions Directorate) – Eglin AFB
Atlantic Research Corporation
Department of Defense Explosive Safety Board
JANNAF (Hazard Classification Panel)
John Hopkins University/Chemical Propulsion Information Agency
Lawrence/Livermore (detonation experts)
Los Alamos (detonation experts)
Naval Air Warfare Center – China Lake
Naval Sea Warfare Center – Indian Head
Pratt & Whitney Chemical Systems Division
Thiokol Propulsion
Tri-Services – Hazard Classifiers
U.S. Army – Space and Missile Defense Command
U.S. Army Research Laboratory – Aberdeen Proving Ground

The results of these workshops will be reported at the JANNAF PSHS Joint Meeting (13-17 Nov 2000). A subsequent workshop will also be held at this meeting.

CONCLUSIONS

The UN test series 6 used to address storage and transportation hazards for class 1 hazard divisions utilize tests for internal ignition, external heating and shock sensitivity. This test series requires full size articles and is cost prohibitive and impractical for large rocket motors. The current alternate tests in the protocol are inconsistent with UN test series 6 in that they don't address internal ignition or external heating. In addition, the alternate shock sensitivity tests are too extreme to represent actual transportation and storage threat concerns, imparting a shock stimulus to the propellant orders of magnitude higher than the worst-case scenarios. The zero cards requirement for all of the alternate tests are also inconsistent with the NOL card gap test used for IHC that uses 70 cards and the EIDS test in UN test series 5 that uses a 70.10-millimeter (2.76-inch) PMMA gap for shock attenuation.

As a result of the DoD hazard classification changes, many solid rocket propellants and motors will have an interim hazard classification of 1.3 and a final classification of 1.1. Many Class 1.3 motors now in production would be reclassified as 1.1 if put into a new DoD system, increasing life cycle costs by tens of millions of dollars.

Before initiating any test protocols for hazard classification, a thorough threat hazard assessment is needed for the intended materials or articles. By assessing the potential storage and transportation threats the articles could be subjected to, the appropriate test protocols could be implemented to address the concerns of internal ignition, external fire and shock sensitivity/critical diameter.

For the present, potential subscale alternate tests have been identified and proposed by members of the solid rocket community that address the properties measured by UN Test Series 6, i.e., internal ignition, external heating and shock sensitivity in a cost effective, representative test protocol. To further assess shock sensitivity/critical diameter concerns, critical diameter tests, modified gap tests with reasonable shock stimuli and expert reviews for high-energy propellants offer a fair, more representative test protocol to the alternate shock tests currently under TB 700-2.

Regarding standardized replacement protocols, the industry as a whole is not ready at this time to come to consensus and recommend new test protocols for a revised TB 700-2. More communication and cooperation will be needed to overcome differing perspectives between the systems safety/hazards and propellant formulator communities. Before this can happen, more funding, testing and modeling will be needed to address such issues as the recommended shock sensitivity test configurations, sample dimensions, input charge dimensions and stand-off distance (attenuation). In addition, the confidence of being able to correlate subscale analog fast cookoff test articles with full-scale articles would have to be validated.

To allow the solid rocket industry to reach consensus on recommended new test articles and protocols, workshops will be held at the appropriate JANNAF subcommittee meetings with representatives from each of the organizations affected by TB 700-2 and from experts in the field of detonation test designs and modeling.

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